Detection of Polarized Light Using Binocular Luster and Its Applications

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***Abstract*— A method for detecting polarized light based on the perceptual phenomenon of binocular luster is presented. The design of an optical instrument called a binocular luster polariscope is described, which uses two orthogonal linear polarizing filters to generate contrast differences between both eyes. From these differences, the visual system allows the immediate identification of the presence of polarized light in a scene. Applications of the method in the discrimination between specular and diffuse reflections, as well as in the identification of metallic materials through human vision and machine vision, are also analyzed. The results suggest that the proposed approach constitutes a simple and effective alternative to more complex instrumental techniques.**

Keywords*— Binocular luster, machine vision, binocular vision, perception, polarized light, polariscope.

I. Introduction

It is known that humans can perceive polarized light without the use of optical instruments through the entoptic phenomenon known as Haidinger's brush, described by the Austrian physicist Wilhelm Karl Ritter von Haidinger. However, the perception of Haidinger's brush is inherently weak and transient, which makes its direct observation under normal conditions difficult. This phenomenon depends on a subtle modulation of polarized light over the macula, so its visibility usually requires controlled lighting conditions, in addition to requiring a certain level of healthy macular function [1]. Thanks to this, we can rule it out as a practical method for detecting polarized light.

In this work, we propose an alternative method for detecting polarized light based on the visual phenomenon known as binocular luster, which is described in Section II. To achieve this, we require an optical instrument that we call the binocular luster polariscope, whose design is presented in Section III. Furthermore, we explore how specular and diffuse reflections could be discriminated in Section IV, and its application in the identification of metallic materials in Section V. Finally, Section VI presents the conclusions of the study.

II. Binocular Luster

Binocular luster was reported by Heinrich Dove in 1851 and is a phenomenon of visual perception that occurs when each eye receives slightly different images, especially in terms of brightness or color, and the visual system integrates them into a single experience. As a result of these differences between the eyes, a sensation of shine or glossy appearance emerges that is not present in either image viewed separately. This quality is perceived as a luminous appearance or similar to surfaces such as metal or glass and arises as an emergent property of the joint processing of visual information from both eyes [2].

To illustrate the perception of binocular luster, we can make use of Figure 1, which must be binocularly fused (presenting half of the image to one eye and the other half to the other eye) in order to perceive the shine appearing in the squares.

III. Binocular Luster Polariscope

A binocular luster polariscope (see Figure 2) is an optical instrument composed of two orthogonal linear polarizing filters, one horizontally oriented polarizer placed in front of one eye (either left or right) and a second vertically oriented polarizer placed in front of the remaining eye. This configuration generates contrast differences between both eyes for the same scene when the light coming from the scene contains polarized components, thus allowing the instantaneous perception of polarized light.

In Figure 3 we can observe the point of view of a user employing the binocular luster polariscope. In order to perceive the visual phenomenon of binocular luster, it is necessary to fuse the stereoscopic pair using the parallel viewing method or with the help of a stereoscope. The binocular luster perceived in the scene would mostly be caused by the existence of polarized light within it, although naturally a small portion of the binocular luster would correspond to what we perceive every day simply because we have two eyes receiving different light intensities from certain objects.

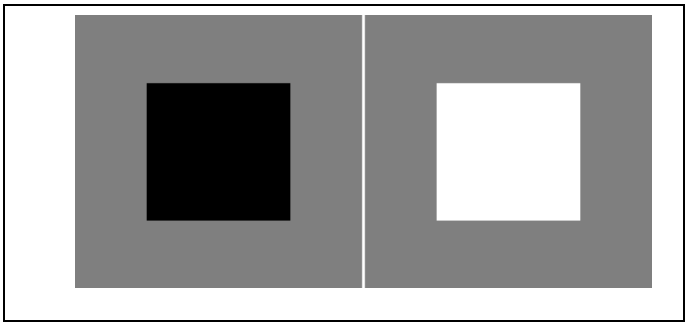

Fig. 1. Image that, when binocularly fused, generates luster in the area where the contrasting squares are located.

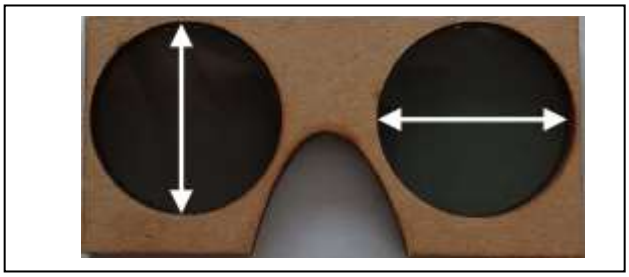

Fig. 2. Binocular luster polariscope.

Fig. 3. Stereoscopic pair from the point of view of a user looking through the binocular luster polariscope.

I would like to emphasize that the design of the binocular luster polariscope must arrange the linear polarizing filters horizontally and vertically, and not at an intermediate angle, even while maintaining orthogonality between both filters. The reason is that most scenes we might observe contain polarized light originating from the reflection of unpolarized light on surfaces, and therefore the horizontal and vertical configuration achieves a maximum intensity for one eye and a minimum intensity for the other in the polarized regions of the scene, creating the high contrast necessary for binocular luster. It should be remembered that, for this reason, sunglasses with linear polarizing filters arrange them vertically to eliminate reflections rather than at an intermediate angle.

There are several criticisms that can be made regarding the optical instrument we call the binocular luster polariscope, which I would like to address next. Some may have immediately recognized that it is equivalent to a certain type of stereoscopic viewer used for observing 3D images; however, we decided to name it a binocular luster polariscope to emphasize its specific functional use for perceiving polarized light and thus distinguish it from its traditional use of generating depth perception. This is like how a convex lens is called a magnifying glass when used to magnify an image, or a collimating lens when used to collimate light rays. Furthermore, at the time of writing this document, I am unaware of any scientific literature describing the use proposed here for this polarizer arrangement, and therefore I took the liberty of assigning it a descriptive name. Another criticism is that the binocular luster polariscope may inherently cause visual fatigue and discomfort, which is true, but in our experience using it, we can compare it to or even say it is less than the discomfort caused by anaglyph glasses.

IV. Discrimination of Diffuse and Specular Reflections

When polarized light is reflected from a diffuse surface, it tends to become depolarized because it is reflected in multiple directions. In contrast, when reflected from a predominantly specular surface, the light may preserve its polarization state to some extent. For this reason, stereoscopic movie projection systems that employ polarized light use silver screens, which exhibit behavior closer to specular reflection, unlike conventional white screens that reflect light diffusely and tend to depolarize it. Using this knowledge, we can infer the following: if we illuminate a scene with a linearly polarized light source and observe the different reflections present in the scene through our binocular luster polariscope, we could instantly identify the parts of the scene exhibiting specular reflection and those exhibiting diffuse reflection, because of the specular reflections would preserve polarization and generate binocular luster in our perception.

V. Identification of Metallic Materials

Since many metallic materials exhibit specular reflection, we can make use of what was described in Section IV to determine whether they are present in a scene illuminated by linearly polarized light. We present two methods using human vision and machine vision, which are explored below.

A. Human Vision

If a user employed an arrangement similar to that shown in Figure 4 and observed the ground at night in places such as parks and gardens, they might encounter scenes like those shown in Figure 5, which present a maximum intensity for one eye because the linearly polarized light reflected by the metal remains aligned with the axis of the polarizing filter, while the other eye would receive a minimum intensity due to the orthogonal orientation. This would give rise to the binocular luster effect mainly where metals are present, since they would exhibit the greatest contrast. This would make it easier to locate semi-buried metals in the ground, although, as can be seen, other objects such as a leaf could also present binocular luster; however, these would easily be discriminated as non-metallic based on our experience.

Fig. 4. Optical arrangement of the binocular luster polariscope and polarized light lamp.

Fig. 5. The images can be binocularly fused to perceive binocular luster. In the upper pair, there is the head of a screw and a leaf, both presenting binocular luster; in the lower pair, only the screw is present and it is the main source of binocular luster.

B. Machine Vision

In the context of machine vision, the use of polarized light for the classification of metallic and dielectric materials has already been investigated [3],[4]. It has also been shown that the presence of polarized light can be identified in an image captured by complex instruments known as polarization cameras [5]. However, we have not found in the references a method as simple as the one proposed below.

A camera captures two images of a scene illuminated by linearly polarized light. In one of the captured images, a minimum intensity is obtained because a linear polarizing filter is placed in such a way that it blocks the polarized light present in the scene. In the other captured image, another linear polarizing filter crossed with respect to the previous one is used so that a maximum intensity is obtained because it allows the polarized light from the scene to pass through. For machine vision to "see" its own version of binocular luster, image processing must be performed on the captured images, which we implemented in LabVIEW. First, the images are converted to grayscale. Then, the lower-intensity image is subtracted from the higher-intensity image, and an appropriate threshold is applied to the resulting difference image so that the brightest regions stand out in a binary image. The result of this processing can be seen in Figure 6, and it is easy to observe that the binary image displays in white pixels the areas of the scene exhibiting specular reflection, which is mainly associated with the metallic materials present.

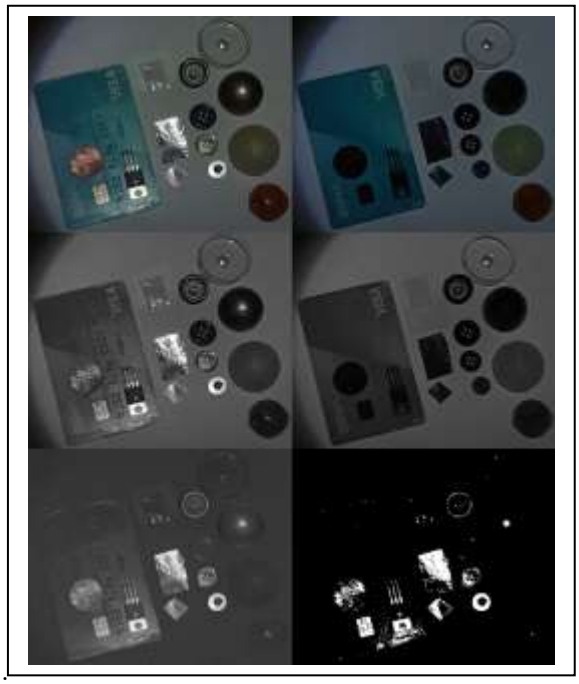

Fig. 6. The upper pair corresponds to the maximum and minimum intensity images respectively, the middle pair shows their grayscale versions, and the lower pair shows the result of the difference between them on the left and the thresholded binary image on the right.

VI. Conclusions

The use of binocular luster as a tool for detecting polarized light represents a novel and accessible alternative to traditional methods. The binocular luster polariscope allows immediate perception of polarization differences within a scene through a simple optical arrangement. It was demonstrated that this principle can be employed to distinguish between diffuse and specular reflections, as well as to facilitate the identification of metallic materials in different contexts. Furthermore, its extension to the field of machine vision through image processing confirms the feasibility of the approach in automated systems.

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